

The background of the cover is a photograph of a large, multi-level concrete bridge spanning a body of water. The bridge features several tall, slender concrete piers supporting the roadway above. The water is a deep blue-green color with some ripples. The sky is a clear, pale blue. The title "CALIFORNIA GEOLOGY" is overlaid on the top half of the image in a large, blue, serif font with a white outline.

# CALIFORNIA GEOLOGY

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# CALIFORNIA GEOLOGY

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Cover Photo. The Coronado Bridge in San Diego Bay. View looking east from Coronado.

Photo by M.P. Kennedy, DMG.



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# LATE QUATERNARY FAULTS SAN DIEGO BAY AND HAZARD TO THE

Michael P.  
California Department of Conserva  
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## INTRODUCTION

**S**outhern California is transected by numerous pervasive northwest-trending Quaternary fault zones. Together they form the broad transform-fault boundary along which the Pacific and North America crustal plates move irregularly past one another in a right-lateral sense at a rate of about 5 centimeters (cm)/year (Figure 1). The city of San Diego, which lies adjacent to the Pacific Ocean in the southwestern-most corner of California, is cut by one such fault zone — the Rose Canyon Fault Zone. Oblique movement on faults within the Rose Canyon Fault Zone has, over time, led to the development of San Diego Bay, which separates the metropolitan area of San Diego from Coronado and North Island (Figure 2).

The Coronado Bridge (Photo 1) spans San Diego Bay and connects the cities of San Diego and Coronado. The bridge is supported by 32 piers, 21 of which (piers 3-23) rest on footings anchored in the bay floor and rise above mean sea level to elevations ranging from 5 meters (m) at Coronado to more than 75 m in the main channel of the bay near San Diego (Figure 3). A principal concern regarding the bridge's earthquake safety involves its proximity, especially of its foun-

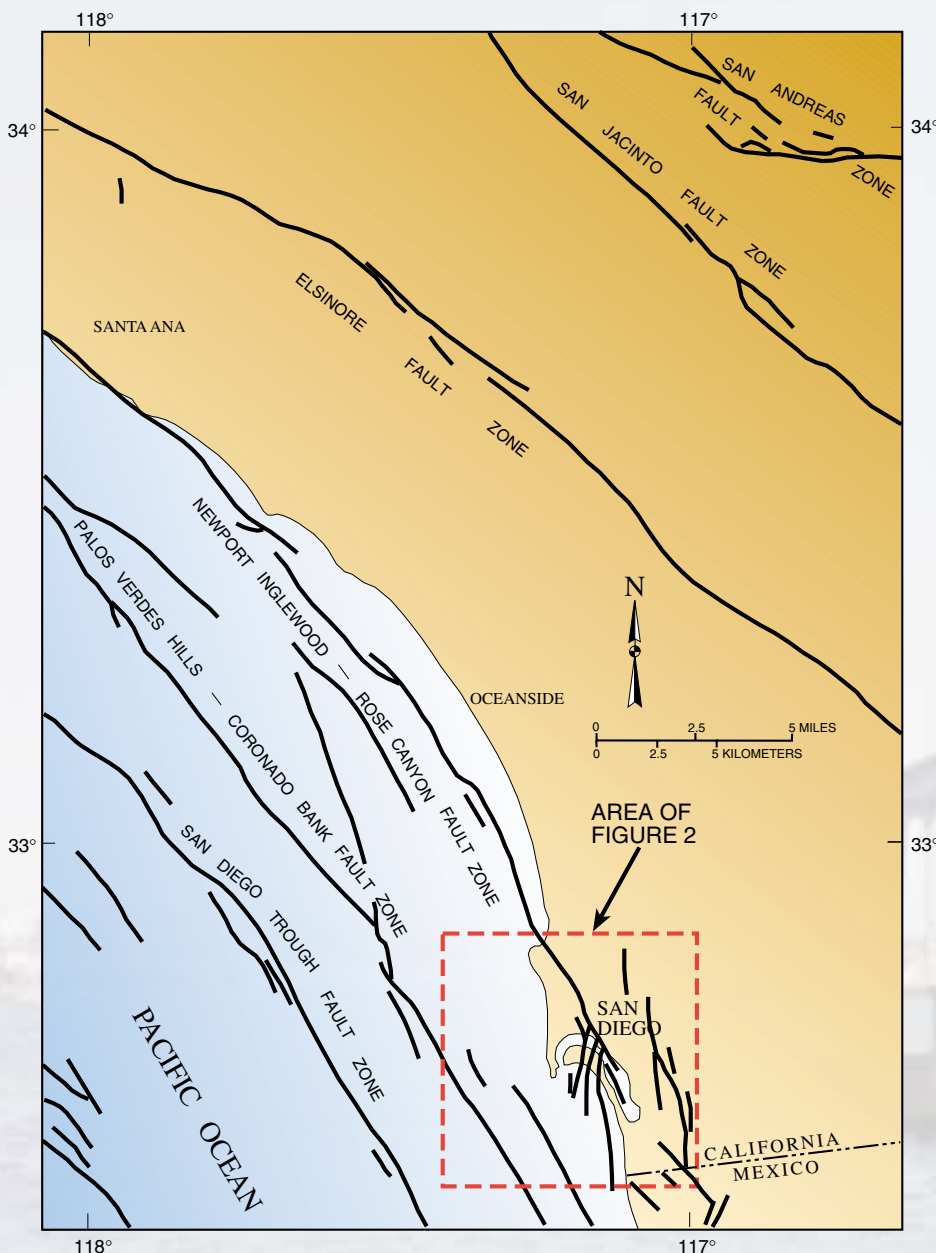


Figure 1. Index map showing major Quaternary faults in southwestern California and the area of Figure 2.

# MULTING IN SAN DIEGO THE CORONADO BRIDGE

by  
George L. Kennedy  
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Geological Survey  
California

dation piers, to potential shallow fault rupture. Our objectives in this study were 1) to identify and accurately locate Holocene faults (those younger than about 12,000 yrs); and 2) to determine the time of most recent movement on these faults and therefore their potential hazard to the Coronado Bridge.

## Method

Our field survey employed the 50-foot research vessel *R/V Tuna* (Photo 2). This ship was chosen because it was small enough to maneuver in and about bridge piers, docks, moorings, and other vessels, while still large enough to carry a substantial amount of seismic equipment on deck (Photo 3). Also, below deck, the ship's laboratory accommodated associated computers, and electronic recording and precision navigational equipment (Photo 4).

About 250 line-kilometer (km) of single-channel, very high-resolution and 130 line-km of multichannel, high-resolution seismic-reflection data were collected for this study. The very high-resolution data shown in Figure 4 were collected using a 350 Joule ORE Geopulse profiling system along tracklines spaced about 100-200 m apart, a spacing that insured unequivocal line-to-line correlations. This system provided

useable subbottom penetration of about 80-90 m, and could resolve subbottom features having a minimum vertical dimension of 0.5 to 1 m. The high-resolution data shown in Figure 5 were collected using an OYO 24-channel seismic recording system and an "airgun" that produced acoustic energy in the water by releasing pulses of high-pressure air ( $14^3$  in @ 1800psi) at 1-second intervals. The high-resolution data were collected at line spacings of 100 to 800 m to study the deeper three dimensional geometries of faults mapped in the near-surface using the very high-resolution data. These data provided about 400-500 m of useable subbottom penetration and about 2-5 m subbottom resolution.

Single-channel Geopulse data were processed using Delph processing software and selected multichannel profiles were processed using ProMAX V5.01 software by Pelagos Corporation. Navigation during both phases of data collection was by differential Global Positioning System (DGPS) and produced meter-level location accuracy throughout the survey.

The California Department of Transportation (Caltrans) drilled 30 core holes beneath the bridge and adjacent to the foundation piers for geotechnical and engineering stud-

ies during the course of our work. Eleven of these borings (Figure 6) were drilled in San Diego Bay from a floating platform (Photo 5). The cores were described, catalogued and archived aboard the drilling platform (Photo 6) and were then transported to a facility where they were subsampled for geologic-age determinations. Age constraints were based on biostratigraphic correlations, radiocarbon dates and amino-acid correlations.

Dr. George L. Kennedy, San Diego State University, identified dateable macrofossil assemblages and extracted fossil materials for radiocarbon dating and for amino-acid correlations (aminostratigraphy). Biostratigraphic ages of approximately 130 macrofossil assemblages reported by Kennedy and Clarke (1997B) were used. Ten radiocarbon dates, which proved essential in constraining the ages of Holocene strata, were determined by Beta Analytic, Inc. of Miami, Florida. The samples and their locations are shown in Figure 6 and reported by Kennedy and Clarke (1997B). Amino acid (AA) analyses, which provided age resolution within upper and middle Pleistocene strata, were carried out by Dr. Julie K. Brigham-Grette, University of Massachusetts (Amherst). Interpretation of these analyses was conducted jointly by Dr. Brigham-Grette



Photo 1. The Coronado Bridge in San Diego Bay. View looking east from Coronado. *Photo by M.P. Kennedy, DMG.*

and Dr. Kennedy. Locations of the AA samples are shown in Figure 6, and details of these data were reported by Kennedy and Clarke (1997B). Twelve core samples were analyzed for their microfossil content by Micropaleo Consultants, Inc. of Encinitas, California. The results were reported in detail by Kennedy and Clarke (1997B) and are summarized here. The application of the fossil-age results to the geological record and to the seismic-reflection data collected, as well as the overall assessment of fault history, is the responsibility of the authors.

### Regional Geologic Setting

The San Diego coastal area that lies between the U.S. International Border with Mexico and Oceanside (Figure 1) is underlain by a thick succession (>3,000 m) of Late Mesozoic and Cenozoic detrital marine, lagoonal, and terrestrial deposits that unconformably overlie an older (Jurassic and Cretaceous age) plutonic and metamorphic basement complex. Rocks of the basement complex do not crop out in the area studied, but are present in the subsurface beneath San Diego Bay (Gray and others, 1971). The basement complex is composed of a wide variety of siliceous metavol-

canic and metasedimentary rocks that have been intruded by plutonic rocks of the Peninsular Range Batholith.

The basement complex is overlain by an Upper Cretaceous marine and nonmarine succession of conglomerate, sandstone, and siltstone that is assigned to the Rosario Group (Kennedy and Moore, 1971). The Rosario Group crops out in a structural high at Point

Loma approximately 5 km west of the Coronado Bridge (Figure 2). This high represents the western margin of the Quaternary basin that has trapped more than 150 m of Pleistocene and Holocene sediment (Figure 4) and that is now occupied by San Diego Bay and its adjacent offshore bight. The Rosario Group is, in turn, unconformably overlain by a succession of Tertiary strata that includes the Eocene La Jolla and Poway groups, the Oligocene-Miocene Otay Formation, the Miocene San Onofre Breccia, and the upper Pliocene San Diego Formation.

Lower Pleistocene and Holocene deposits overlie Tertiary strata in the coastal San Diego region. Most of this Quaternary sediment has been derived from older rocks that now underlie and form the coastal highlands of the area. The Quaternary strata are composed almost entirely of medium- and fine-grained sandstone and siltstone that were deposited in shallow-water marine, estuarine, and deltaic environments. These deposits are homogeneous; differentiation between units is difficult. Color, grain size, degree of lithification, and mineralogy differ little between individual units en-



Photo 2. The R/V *Tuna* near the Coronado Bridge in San Diego Bay. View looking northeast toward the San Diego Civic Center. *Photo by M.P. Kennedy, DMG.*

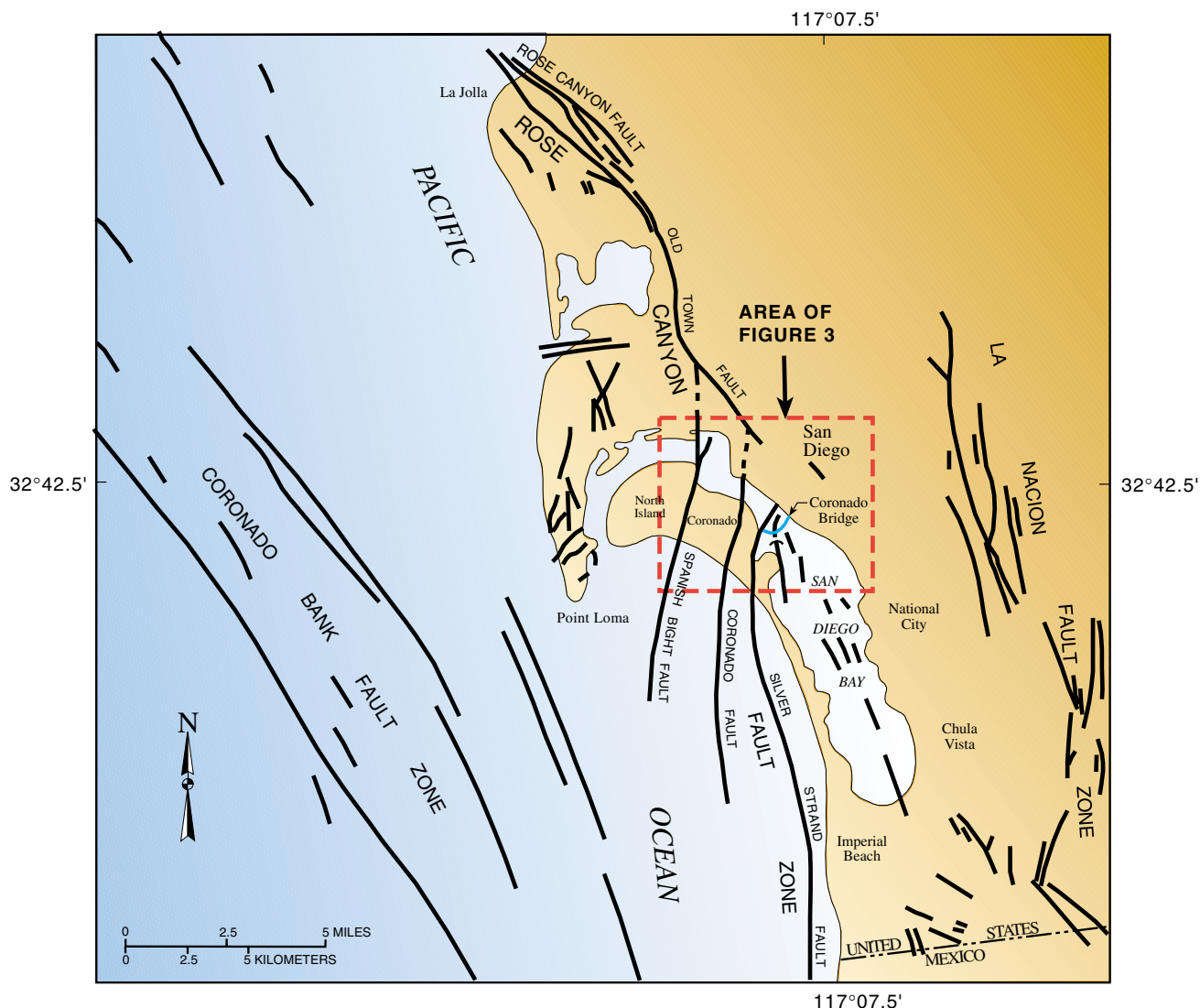


Figure 2. Index map showing the locations of faults in the San Diego coastal area and the area studied for the report (see Figure 3).

countered in the cores collected in San Diego Bay.

Faults mapped in the study area lie within the Rose Canyon Fault Zone as depicted by Kennedy and others (1975), Moore and Kennedy (1975), Kennedy and Welday (1980), Clarke and others (1987) and Treiman (1993). The Rose Canyon Fault Zone cuts Holocene sediment in Rose Canyon, 7 km north of San Diego Bay where a late Pleistocene slip rate of 1-2 millimeters (mm)/yr has been estimated, (Lindvall and Rockwell, 1995); it is seismically active in the region of our study (Simons, 1977). Geologic mapping of the Rose Canyon Fault Zone in the onshore coastal San Diego area (Kennedy, 1975) dem-

onstrates that the Upper Cretaceous and Paleogene sedimentary sequences are offset substantially greater amounts than are the overlying Neogene beds and, in turn, the Neogene section is offset to a greater degree than are the Quaternary units. These offsets suggest a long-term Tertiary slip rate of about 1-2 mm/yr (Kennedy and others, 1975). These data combined with similar observations in the seismic records indicate that there has been a relatively long history of faulting associated with the Rose Canyon Fault Zone.

#### Faulting

Major fault zones in southwestern California are characterized by

a strong northwesterly trend (Figure 1). Most of the principal faults mapped in the San Diego coastal area also trend northwesterly. Exceptions include: 1) faults east of San Diego within the La Nacion Fault Zone, which have a more northerly (on average) trend; and 2) several major and minor faults within the Rose Canyon Fault Zone in north central San Diego Bay, on Coronado Island, and in the offshore bight, which trend north to north northeast (Figure 2). The northeast-trending faults that underlie San Diego Bay were the focus of this study. The most prominent of these include from west to east, the Spanish Bight, Coronado and Silver Strand faults (Figure 2). We have mapped three segments of the Silver

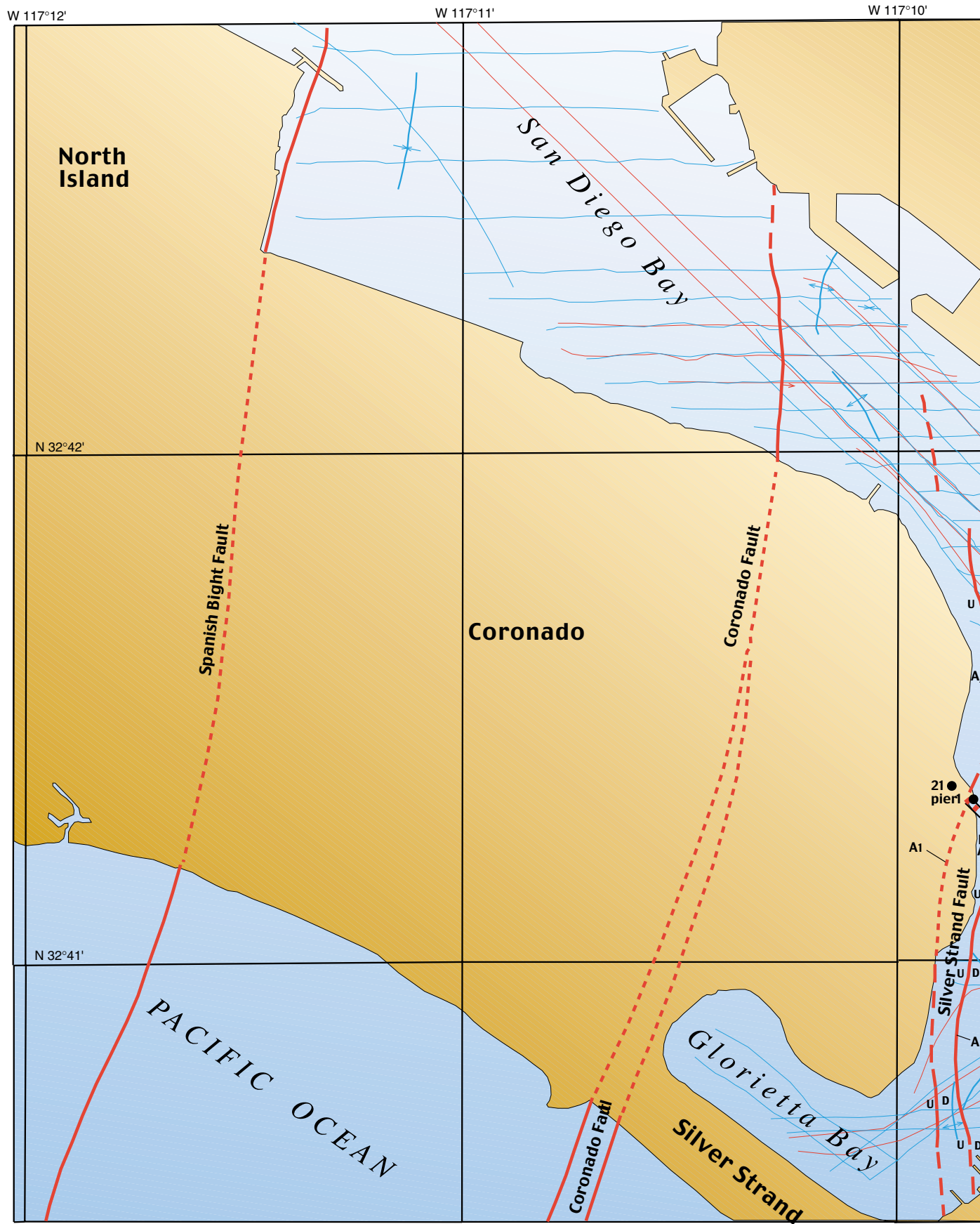


Figure 3. Map showing the location of faults, folds, core holes, geophysical tracklines and pier pilings in the vicinity of the Coronado





Photo 3. Air compressor, generator and hydrophone streamer reel mounted on the aft deck of the *R/V Tuna*. Photo by S.H. Clarke, USGS.

Strand Fault and labeled them A1, A2 and A3 (Figure 3). In addition, eight other faults labeled B1, B2, B3, C1, C2, D1, E1 and E2 have been mapped east of the Silver Strand Fault in the central part of San Diego Bay beneath the Coronado Bridge (Figure 3). Together these faults form a complex graben (San Diego Bay graben) that underlies San Diego Bay. Gravity (Kennedy and others, 1994), seismicity (Simons, 1977), and geophysical data (Kennedy and Clarke, 1997A) have been used to define its approximate boundaries, tectonic character and recency of movement. In particular, the gravity data of Jachens and Langenheim (Kennedy and others, 1994) show a major oval-shaped gravity low that has its long axis sub-parallel to the long axis of San Diego Bay. The presence of this gravity low indicates that a substantial, sediment filled basin exists below the bay. We suggest that regional right shear along such structures as the Newport-Inglewood-Rose Canyon and Coronado Bank fault zones (Figure 1) has developed a pull apart basin within which normal faulting and closely related tensional faulting at depth have occurred.

### *Spanish Bight Fault*

One of the most conspicuous faults mapped is the Spanish Bight Fault (Figures 2 and 3). The Spanish Bight Fault extends southward about 13 km from the Old Town segment of the Rose Canyon Fault Zone to a point about 6-7 km south and offshore from North Island (Figure 2). In the area of our study, the principal strand can be followed continuously as a single break from Harbor Island to North Island (Figure 2). A

branch splays northeasterly from near the shoreline at North Island and extends 1 km into the bay before dying out. The principal trace of the Spanish Bight Fault is characterized by a northerly trend and a 75° E dip, and extends upward to within 5-10 ms (~ 4-8 m) of the bay floor (Kennedy and Clarke, 1997A). Note: an average seismic velocity of 1600-1700 m/sec was used to convert acoustic travel time to stratal thickness.

### *Coronado Fault*

The Coronado Fault parallels the Spanish Bight Fault and crosses San Diego Bay as a single north-trending break 1.4 km northwest of pier 1 of the Coronado Bridge (Figure 3). The location of the fault farther to the north is unknown but, based on a projection along strike to the north, it may intersect or join the Old Town segment of the Rose Canyon Fault (Figure 2). It has been mapped to the south across Coronado Island and offshore from Silver Strand for approximately 10 km (Kennedy and Welday, 1980). Within San Diego Bay, the Coronado Fault strikes N 5° E and dips steeply (near vertical) to the southeast from the bay floor to a depth of approximately 200 ms (~ 160



Photo 4. The electronic equipment used to record and navigate seismic data were secured below deck in the laboratory of the *R/V Tuna*. Photo by M.P. Kennedy, DMG.

m). From 200 to 500 ms ( $\sim 160$ -425 m) the dip of the fault decreases to approximately  $73^\circ$  E. The Coronado Fault cuts material at or very near the bay floor and is considered to be one of the most youthful faults in this part of the Rose Canyon Fault Zone (Kennedy and Clarke, 1997B).

### Silver Strand Fault

The Silver Strand Fault has three elements that are shown in Figure 3 as faults A1, A2, and A3. Faults A1 and A2 are, for most of their lengths, subparallel to the Coronado and Spanish Bight faults. They have a northerly trend from at least the U.S./ Mexico border, across the Silver Strand and Glorietta Bay, to a point near the westernmost abutments of the Coronado Bridge (Kennedy and Welday, 1980). Fault A1 crosses beneath or lies very close to pier 1, and fault A2 lies beneath pier 5 (Figure 3). These faults gradually change strike from nearly north-south to  $N 45^\circ E$  between Glorietta Bay and the eastern shoreline of San Diego Bay (Figure 3). Near the bridge and within the central bay area both faults dip to the southeast at an apparent (minimum dip) angle of about  $50^\circ$ . In addition, both faults extend upward to within 5-10 ms ( $\sim 4$ -8 m) of the bay floor in an area that is undergoing rapid sedimentation. The materials that cover the fault are very youthful (Holocene), water saturated, "bay mud" that would tend to behave as a liquid when shaken, so that evidence of most recent fault rupture may not be preserved. Fault A3 dips steeply to the west and may join faults A1 and A2 at depth (Kennedy and Clarke, 1997A). It, too, extends upward to within proximity to the bay floor. Together these faults may be part of a negative flower structure developed in the area of the Coronado Bridge by transtension within a regional Holocene right-slip fault system, possibly involving other major faults, such as the Coronado Bank Fault Zone and/or an as-



Photo 5. Drilling platform and equipment used to obtain cores. *Photo by M.P. Kennedy, DMG.*

yet unidentified principal eastern strand of the Rose Canyon Fault System. We believe that faults A1 and A2 together represent the northwestern margin of the San Diego Bay graben.

Faults B1, B2, and B3 parallel the Silver Strand Fault Zone in the central part of the bay (Figure 3). At the bridge, fault B2 lies beneath pier 14, fault B3 lies beneath pier 17, and fault B1 crosses between

piers 12 and 13 (Figure 3). These are normal faults that have formed in the same manner as faults A1 - A3; fault blocks formed between faults A1 and B3 typify small-scale incipient hanging-wall normal-fault displacements associated with regional tensional deformation. Faults B1, B2, and B3 are normal faults that lie within and form part of the western margin of the San Diego Bay graben. Fault B1 dips  $75^\circ$  E and has associated down-to-the-



Photo 6. Cores being described, catalogued and archived by Caltrans personnel aboard the drilling platform shown in Photo 5. *Photo by S.H. Clarke, USGS.*

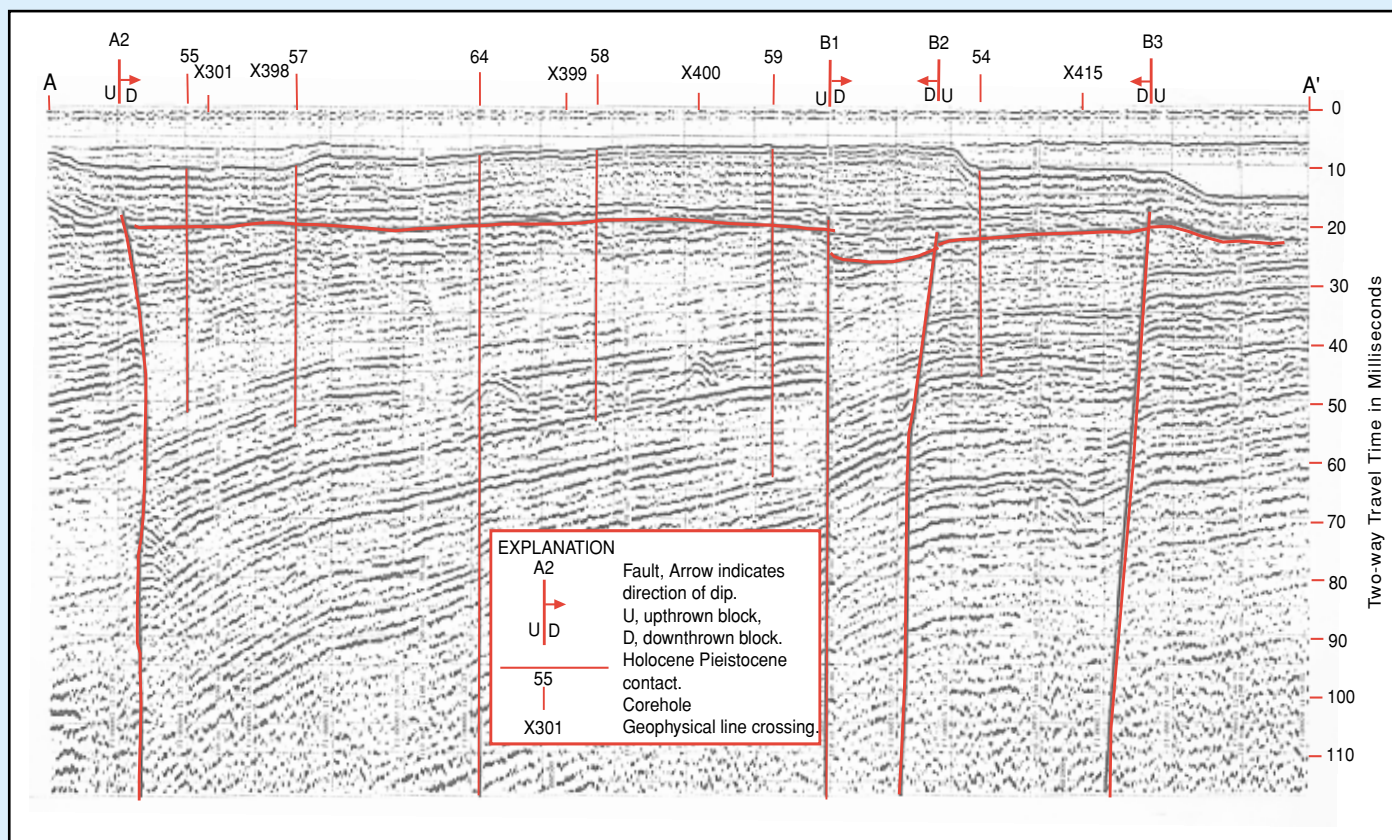


Figure 4. Very high-resolution 350 Joule ORE Geopulse seismic-reflection profile showing the Holocene-Pleistocene boundary and approximately 100 m of Quaternary sediment cut by faults A2, B1, B2 and B3 in the vicinity of the Coronado Bridge (see Figure 3 for location).

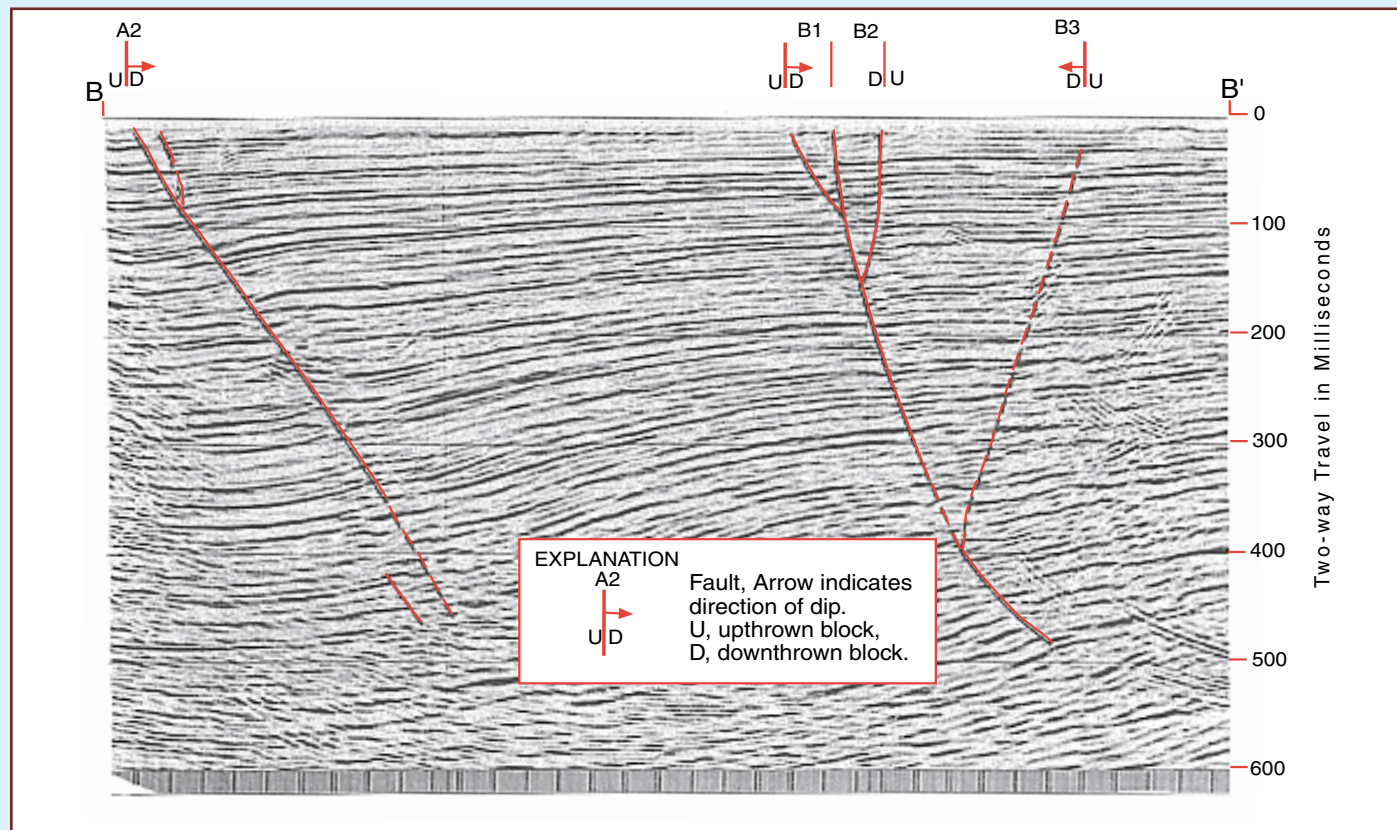


Figure 5. High-resolution, 24 channel seismic-reflection profile showing approximately 0.5 km of (mostly or wholly) Quaternary sediment cut by faults A2, B1, B2, and B3 in the vicinity of the Coronado Bridge (see Figure 3 for location).

east movement, whereas faults B2 and B3 dip steeply to the west and have associated down-to-the-west movement. The west-dipping faults move to fill the void being developed by regional extensional tectonics. The east-dipping faults form and bound mini-grabens along the flanks of the larger, central San Diego Bay graben. Fault rupture extends to within 15-20 ms (~ 12-16 m) of the bay floor on fault B1, and to within a similar distance (10-15 ms; ~ 8-12 m) on B3, suggesting to us that these faults are very youthful and closely similar in age (Kennedy and Clarke, 1997A)

Faults C1 and C2 do not cross beneath the Coronado Bridge but converge at a point approximately 200 m southwest of the bridge (Figure 3). Fault C1 strikes N 45° E, dips nearly vertically to steeply southeast, and extends to within at least 20-25 ms (16-20 m) of the bay floor (Kennedy and Clarke, 1997A). Fault C1 is very similar in overall character to fault B1. Fault C2 strikes almost north-south until it merges with fault C1, at which point it acquires the N 40° E strike of fault C1. Fault C2 dips approximately 65°-70° east along most of its length, extends to within 5-10 ms (4-8 m) of the bay floor, and has faulted sediment down to the east and into the San Diego Bay graben. Fault D1 strikes N 5° -10° W and merges with fault C2 approximately 500 m southeast of the Coronado Bridge. Fault D1 is nearly vertical along its entire length and differs from faults C1 and C2 in that it displaces sediment down to the west, which has formed a small graben between faults D1 and C2 (Kennedy and Clarke, 1997A). This relationship is analogous to that seen between faults B1 and B2 in the vicinity of Coronado Bridge piers 12, 13, and 14. Fault D1 extends to within about 10 ms (~ 8 m) of the bay floor and appears to be a youthful, major north-south trending fault within this overall structural framework (Figure 3). Fault D1 may extend southward

across Silver Strand into the offshore beyond the coverage of our data. It may also form a major structural division within the bay between northeast-trending structures to the northwest and north-trending structures to the southeast.

An open, north-trending anticline extends between fault D1 and faults E1 and E2. Faults E1 and E2 (Figure 3) lie parallel and adjacent to fault D1 and to the intervening anticline. These faults may lie within the eastern margin of the San Diego graben. Fault E1 strikes N 5° E and dips 70° W. It displaces youthful strata down to the west and cuts materials within 5-10 ms (~ 4-8 m) of the bay floor (Kennedy and Clarke, 1997A). Fault E2 parallels fault E1 approximately 200 m to the east, dips 70° W, displaces sediment down to the west, and may cut strata to within 15 ms (~12 m) of the bay floor.

#### Age of Faulting

Radiocarbon dating, aminostratigraphy and paleontologic analyses were conducted on molluscan shell material from core samples collected beneath the Coronado Bridge to determine the age of faulted sediment. The locations of the faults, core holes, and core-hole samples, as well as the ages of these samples are shown on Figure 6, a cross-sectional profile drawn along the alignment of the bridge (Figure 6). This profile also shows the stratigraphically lowermost occurrence of dated Holocene shell material and the uppermost occurrence of dated Pleistocene shells. These age determinations were used to establish the Holocene-Pleistocene (H/P) boundary shown on Figure 4 and on previously published seismic-reflection profiles from the vicinity of the bridge (Kennedy and Clarke, 1997B).

The oldest Holocene age among the ten radiocarbon dates obtained from samples beneath the western part of the Coronado Bridge is  $6325 \pm 85$  14 C yr B.P.

(CB4, Figure 6). This sample was collected from a bed at or very near the Holocene/Pleistocene boundary. This suggests a maximum age for Holocene strata in this area, and indicates that faults shown in our data and discussed here as cutting the H/P boundary have been active more recently than about 6400 14 C yr B.P. — clearly during late Holocene time. This date, therefore, can be used as a maximum age of most recent fault activity. Five additional other shell samples collected from beds at or very near the base of the Holocene section cluster within an age range from  $4875 \pm 70$  14C yr B.P. to  $6005 \pm 70$  14 C yr B.P. (Figure 6). Consequently, we conclude that the oldest Holocene strata within this part of San Diego Bay are probably less than about 6,500 years in age, and that older Holocene strata (~6500-12,000 yr B.P.) are not represented here. This is consistent with the area of the bridge having occupied very shallow marine or estuarine environment during the peak flood of the Holocene transgression, which occurred about 6,000 yr B.P. in southern California.

The minimum age of recent fault activity (i.e., time of most recent fault movement) has not been established from our study. However, the youngest dated sequence known to be faulted is  $4435 \pm 115$  yr B.P. (CB8, Figure 6) and was collected from the middle to upper part of the Holocene section. Clearly, some faults extend to the uppermost Holocene strata (Kennedy and Clarke, 1997B), indicating fault activity that is more youthful than our youngest date. However, the detail of dating necessary to more closely constrain the time of most recent faulting was beyond the scope of the study. It is also important to note that evidence of rupture can be obscured by the "homogenization" of youthful water-saturated sediment due to ground shaking accompanying earthquake-related fault movement, so that fault planes and small offsets may not be visible in

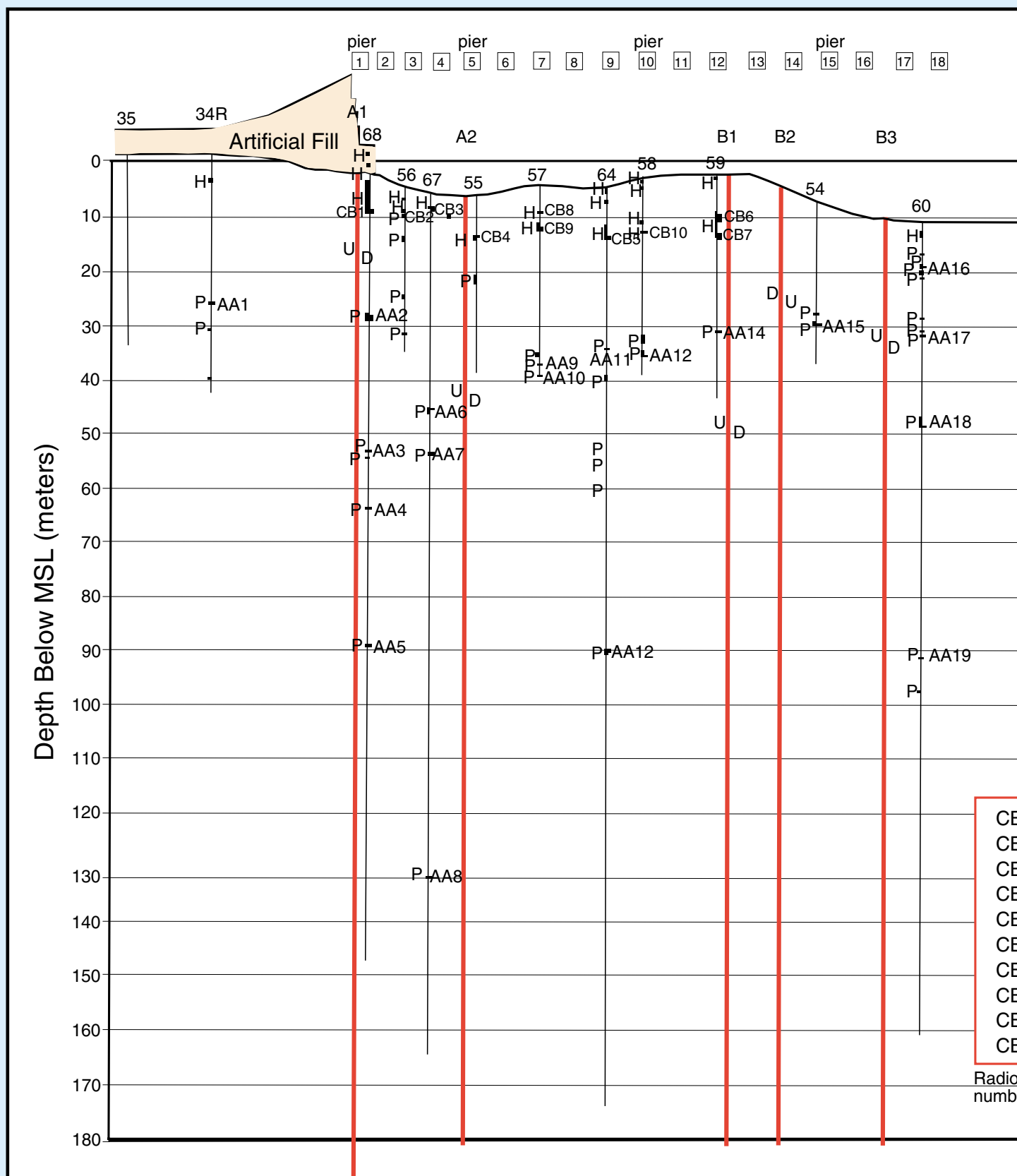
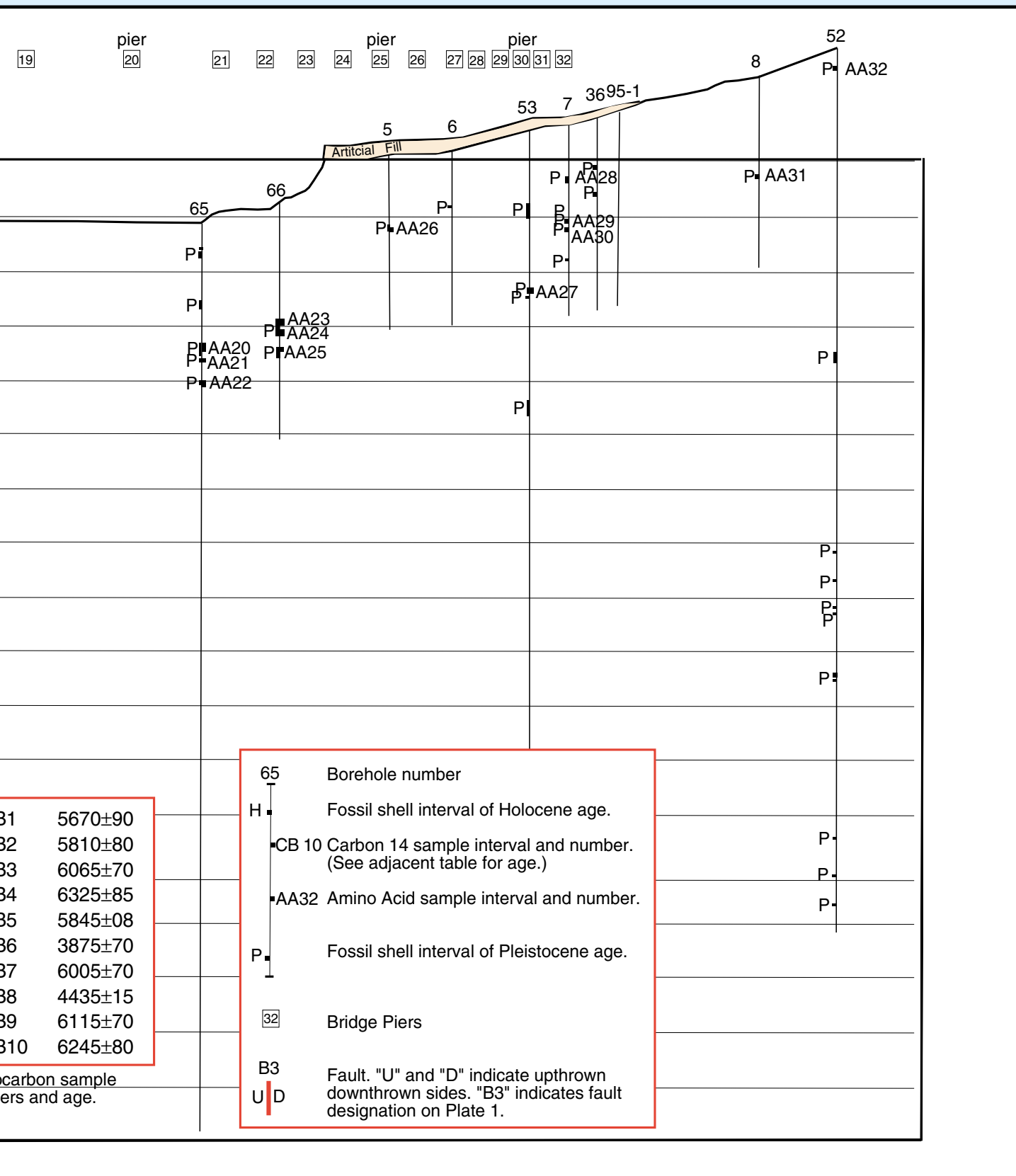


Figure 6. Cross section of San Diego Bay along the centerline of the Coronado Bridge showing major faults, core holes, radiocarbon



dates, locations of AA samples, and the locations of Holocene and Pleistocene shell material.

the uppermost parts of the seismic-reflection records that form the core of our data.

Nine faults cut the H/P boundary in the vicinity of the Coronado Bridge. Five of these faults (A1, A2, B1, B2 and B3) cross beneath the bridge and four (A3, C1, C2 and D1) lie in proximity (300-500 m) to the bridge (Figure 3). It is noteworthy that the H/P boundary is faulted at some locations and not at others along the strike of these faults (Kennedy and Clarke, 1997B), which suggests that the upper limit of rupture varies spatially throughout the fault system.

On the west side of the bay and near the shoreline of Coronado Island, fault A1 is inferred to lie beneath pier 1 and fault A2 was mapped beneath pier 5 (Figure 3). The location of fault A1 is inferred because it is onshore and east of our seismic lines in the immediate vicinity of pier 1. However, it is observed to cut Pleistocene sediment 300 m northeast of pier 1, and to extend upward to within 5 ms (~ 4 m) of the bay floor and to questionably cut the H/P boundary 700 m northeast of pier 1 (Kennedy and Clarke, 1997B). Fault A2 clearly cuts the H/P boundary along most of its observed length. It extends to within 7-8 ms (~ 6 m) of the bay floor at pier 5 and to within 5 ms (~ 4 m) of the bay floor 60 m north of pier 5 (Kennedy and Clarke, 1997B). East of and subparallel to the Silver Strand Fault, fault B1 crosses beneath the bridge

between piers 12 and 13, fault B2 at pier 14, and fault B3 at or very near pier 17. Faults B1 and B2 cut the H/P boundary beneath the bridge (Kennedy and Clarke, 1997B), whereas fault B3 cuts only Pleistocene strata in its closest location to the bridge. However, 200 m south of pier 17 fault B2 cuts the H/P boundary and extends to within 7 ms (~ 6 m) of the bay floor (Kennedy and Clarke, 1997B).

Because faults A3, C1, C2 and D1 do not pass beneath the bridge, they do not pose the same kind of ground rupture hazards as do faults A1, A2, B1, B2 and B3. However, they are an integral part of the Holocene tectonic fabric of San Diego Bay and would likely accommodate a portion of the strain produced by earthquakes generated on the Rose Canyon Fault Zone.

## CONCLUSIONS

1. Two faults (A1 and A2) of the Silver Strand segment of the Rose Canyon Fault Zone cross the west end of the bridge between the western bridge approach and pier 5. Fault A2 appears to directly underlie pier 5, and fault A1 lies either very close to or beneath pier 1 (Figure 3).

2. Two ancillary faults (B2 and B3) lying between the Silver Strand Fault and a major north-trending fault approximately mid-bay in the vicinity of the bridge appear to closely approach or underlie the foundations of piers 14 and 17, and

a third fault (B1) extends between piers 12 and 13 (Figure 3).

3. One and possibly two north-trending faults south of the bridge trend toward the east end of the bridge (faults E1 and E2, Figure 3). These faults extend shoreward and are projected to lie approximately 1 km south of the eastern approach to the bridge. Their possible continuity on land, and their relationship to a possible extension of the Old Town segment of the Rose Canyon Fault Zone and to previously mapped short north-trending faults in the southern part of San Diego Bay are presently unknown, but should be investigated.

4. The style of faulting we observe appears to be consonant with extensional opening of the bay along generally north- to northeast-trending normal faults (e.g., the Spanish Bight, Coronado, and Silver Strand faults) that are subsidiary to a north-northwest trending right-lateral wrench system that is probably formed by the Rose Canyon Fault (*sensu strictu*) and by a fault or faults lying offshore—perhaps elements of the Coronado Bank Fault Zone.

5. Faulted Holocene sediment beneath the bridge consists of a fine-grained, estuarine sequence that is approximately 6,500 years old at its base. The youngest dated materials that are faulted are 4435 ± 115 years, although faults occur higher in the section in stratigraphically younger deposits.

## ACKNOWLEDGMENTS

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# SURPRISING MUSEUM

## AN HISTORY OF SHOSHONE

by

Pamela

### INTRODUCTION

The tiny town of Shoshone sits on the southeast rim of Death Valley National Park (DVNP). After the long, nearly barren drive north from Baker, the casual tourist might notice the welcome green of its tamarisk and palm trees, but, intent on gaining entrance to DVNP and its wonders, may barely glance at the collection of modest buildings that briefly line either side of the road. Too often, harried tourists won't even notice the small, weather-worn building with its unpretentious sign — Shoshone Museum — yet anyone interested in natural or human history will be amply rewarded for taking time to pause here.

Perhaps most surprisingly, unlike so many roadside souvenir shops that display a few local relics and proclaim themselves “museums” to entice the tourists, this really is a museum. Despite its small interior and uneven, original wood floors, the visitor will soon learn that the collection is well thought-out, pleasingly displayed and truly representative of the area's interesting past.

### THE MUSEUM

The museum, like the valley, represents a broad spectrum of natural history. The common thread is locale; everything earns its place because it comes from the valley, which was the site of Tecopa Lake until 200,000 years ago. Shoshone sits roughly in the middle of the prehistoric lakebed, surrounded by wonderful caches of plant and animal fossils. You'll find the most spectacular of these, a nearly complete mammoth, at the rear of the museum in a cavernous new room built especially to serve as the mammoth's home. Dating from the Pleistocene Ice Age, this magnificent creature met his demise just south of Shoshone sometime between 100,000 and 300,000 years ago.

During spring break in 1982, four undergraduate geology students from Sonoma State University explored the Tecopa Lake bed for fossils. They spied the circular pattern of fossil remnants; they suspected the end view of a buried tusk. They excavated the remains and moved their prize to Sonoma, where the mammoth was displayed in the lobby of the geology building. It remained there until the opportunity arose, in 1994, to bring it “home.” Strong community support and local funding made it possible for the Shoshone Museum to build the addition and to transport the mammoth back, nearly to the very

place it had rested for eons. It is impressively displayed—not artificially pieced together—but reposing majestically in the dry desert soil, just as it was unearthed. One can almost sense the exuberance of the students who carefully brushed away the barren dust to expose the find of a lifetime.

Around the periphery of the large room are several glass display cases, most of which came from the old borate mine at Ryan and were donated by the Death Valley Forty-Niners. Two cases house a broad representation of local minerals; several good samples of coemanite, chalcedony, boron minerals, talc, turquoise and amethyst are displayed along with an excellent chunk of smoky quartz with feldspar, among others. Another case holds well-prepared casts of mammal footprints—wolf, mammoth, horse, camel—left in the marshy soils around the ancient Tecopa Lake.

In the archway dividing the two rooms, human and natural history again meld in a case displaying the tools and writings of Levi Noble. Dr. Noble was not the first geologist to enter the valley, but perhaps the first to recognize and begin to record its significance. Beside the case sits Dr. Noble's three-legged field sketch board that accompanied him across broad stretches of Death Valley, dutifully providing a perch for recording his findings.

# MUSEUM IN THE DESERT

## AND

# SHOSHONE, CALIFORNIA

Handy

In time, the room will contain additional natural history displays. At the moment the staff and friends of the museum are planning the long-awaited arrival of adequate lighting, modified to protect the delicate fossil bones from damage. The original part of the building contains an array of household furnishings from early Shoshone and Tecopa homes, ranging from a well-preserved coal stove and early “agitator washer” to a well-worn Singer treadle sewing machine. The collection allows a fascinating glimpse of daily life in the desert more than a half a century ago. Here and there, pieces of time-scarred equipment from nearby borax works and gold and silver mines help bring the human history of the Death Valley area to life. A great collection of old local photos, including a pictorial history of the building, rounds out the picture of early Shoshone.

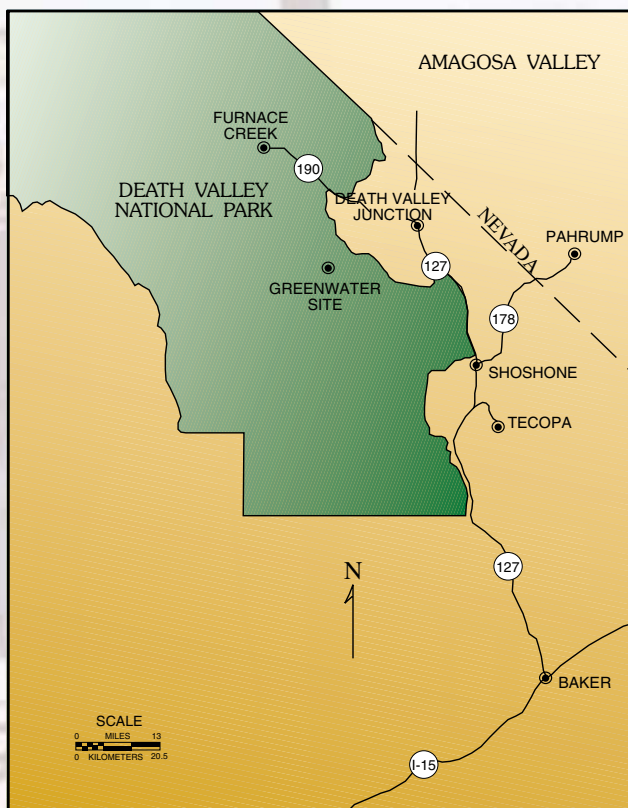
Outside the building, you can poke about in a collection of larger antique farming and mining equipment. Everything is from the surrounding valley. The more puzzling items are accompanied by interesting explanatory signs. The geology student’s prize however, is the “Rock Trail.” Geologist Bennie Troxel and museum volunteer Ken Lengner constructed this deceptively simple illustration that is as fascinating to the lay person as it is to a more experienced geologist seeking a comprehensive overview

of the nature of the valley. Sixteen log “pedestals” display key rock specimens that illustrate the geological history of Death Valley. Pedestal “1” displays an example of 1,700 million-year-old gneiss, the oldest rock in the Death Valley region, formed when the deeply buried crustal rock was metamorphosed. Each succeeding pedestal holds a distinctive rock unit accompanied by a clear and concise description of the rock’s makeup, origin, age, and where it can be found in the local area. Constructed from rocks Troxel

has been studying and gathering for 50 years, it is unique to the Shoshone Museum. It’s a must for any Death Valley visitor who is interested in more than just attractive vistas and intriguing shapes and colors.

### THE AREA

From its birth in 1906 in the mining boomtown of Greenwater 38 miles up the road, the museum building itself has played a pivotal role in the valley. When silver and gold gave birth to the town of Tonopah, Nevada in 1900, it began a frenzied decade of great camps. They sprang from hopes, greed and barren earth wherever precious metal was found in the Nevada/California desert. Greenwater was born when Arthur Kunze found a promising chunk of copper-bearing rock high in the Black Mountains, which form the eastern wall of central Death Valley. Never mind that it was in the brutal heart of the desert, 150 miles from the nearest railroad; Greenwater was going to be bigger than Butte, Montana. Hundreds of





Mountain-top view of the tiny town of Shoshone, California. The museum is on the far right, behind the row of palm trees. *Photo by Fred Handy.*

people poured into the camp and the new town grew even faster than the hole in the mountainside. While some men came to dig, others came to provide the stuff they needed to survive: food, shelter, equipment, spirits, entertainment—even water.

Among the first to arrive was R.J. “Dad” Fairbanks, who had a keen eye for opportunity. The small, stagnant green spring that gave the new town its name was hardly adequate for tens of hundreds of thirsty miners, so Fairbanks headed for Furnace Creek and hauled fresh water 40 miles back up the hill. At a dollar a bucket, he soon had enough money to start a store, feed yard, hotel, and a popular bar. His wife, Celesta, was a fine cook and Fairbanks’ enterprises thrived. His beautiful daughter, Stella, caught the eye of the local sheriff, a lanky, quiet young Georgian by the name of Charles Brown. “Dad” didn’t think much of the lad whose temperament was so different from his, but Stella did, and the two men began an unlikely partnership that

would last a lifetime. Unfortunately, the copper prospects that had inflamed the imaginations of more than 2,000 men never lived up to the promise.

Within 2 years the fortune-seekers moved on, leaving little besides empty buildings. Fairbanks bought up most of those. Because wood was scarce and costly in the desert, buildings were frequently taken apart and moved to the next new town. Fairbanks did exactly that. He hauled the remnants of Greenwater 38 miles south to a little town near the Amargosa River owned by the Pacific Coast Borax Company—Shoshone. Over time Fairbanks’ skill and hard work paid off, and his store, boarding house and restaurant thrived. In 1923, he passed the leasehold on to his daughter, Stella. Shortly afterward her husband seized the opportunity to buy the town and many acres around it from the borax works. Charles and Stella Brown would live out their lives in the small oasis, except for the sessions Charlie spent

serving as a senator in the California legislature. Over time, while the desert is hard on things man-made, one small clapboard building, the last remnant of Greenwater, still survives.

The Browns of Death Valley survive as well. Charles and Stella’s daughter, Bernice, took her turn running the town, and passed it on to her daughter, Susan Sorrells. Today, while it is still a sleepy little backwater, Susan has managed to keep the town on a reasonably solid footing. The family is still committed; Susan’s nephew, Michael (Charles Brown’s great-grandson) helps manage the town and her cousin, Brian Brown, operates the oasis and date farm at China Ranch in nearby Tecopa.

By the late 1980s, the history-filled little building that had arrived in Shoshone to serve as a general store and gas station stood empty and shuttered; Susan and Brian decided to give it still another persona.

They wanted to preserve the history of the town, as well as their own

family's. In doing so, they created a museum that chronicles the human impact on the desert for the past 100 years.

### Shoshone's Geologists

There is one unusual aspect of the small town of Shoshone — it is the winter home of two of the most knowledgeable and respected geologists ever to have explored Death Valley. While both would scoff at the idea that they might equal the renowned Levi Noble, they are legends in their own right, especially to the hordes of young geology students who flock to the valley each winter.

In 1952, Lauren Wright, then head of the Los Angeles office of the Department of Natural Resources, Division of Mines (currently the Division of Mines and Geology), hired another young geologist by the name of Bennie Troxel. The two men could not have been more different in their backgrounds, interests or even appearance. Indeed, they shared little except a love of geology—and of Death Valley.

Soon they were spending many weekends mapping the valley together. Weekends led to weeks, then to winters. Fifty years later, both men, now in their eighties, are still out there, together, examining the geologic history nature has left exposed in this extraordinary place. More importantly to the story, they have also become equally woven into the fiber of Shoshone.

Brian and Susan, while not geologists themselves, still share a deep appreciation of the special and unique place where they have spent most of their lives. It was logical for them to consider including the natural history of the area in the scope of the museum and to draw on their long acquaintance with Troxel and Wright. The two geologists were asked to join the board of the fledgling museum. Others who cared about the area lent their expertise and resources as well. Bob Reynolds, a paleontologist, advised on which minerals to display, and provided several excellent specimens and cast-off cases for displaying them. Jan Tarble joined the board, also. Although self-trained,

her intimate knowledge of the birds native to the Tecopa Lake area is unrivalled. John Cooper, a geologist on the faculty at the University of California at Fullerton rounded out the board, and the historical integrity of the little museum was all but guaranteed.

More than a decade later, those same seven people are still involved on every level imaginable. When floorboards needed replacing, board members were down on their hands and knees, swinging hammers. Recently, Troxel came in with two contributions: a fossil rock he'd found with an excellent footprint of a prehistoric bird, and \$40, proceeds from the aluminum cans the locals collect for him.

### The First Inhabitants

When the Forty-Niners stumbled into the valley looking for a quicker way to the California goldfields, they were fortunate to escape with their lives. Few had any desire to return to this terrible place so inhospitable to life. They weren't the first to come, however; the Shoshone and Paiute



The mammoth is displayed just as it was unearthed in 1982. *Photo by Fred Handy.*



Animal tracks from the ancient Tecopa Lake bed. *Photo by Fred Handy.*

had been here for perhaps several centuries, scratching an existence from the harsh and arid land. Warily, they watched the white men trek across the land they called Tomesha or “land afire.” Sometimes they helped, often they faded into the hills, waiting for the newcomers to pass on. The newcomers eventually returned, of course, and learned to survive in, and love, the desert just as their predecessors had. It’s not a story history has hurried to tell, however; after all, they were “just Indians” according to the popular culture of the early twentieth century. That’s not a viewpoint Susan Sorrells accepts, however. The museum is slowly developing an interesting—and accurate—picture of

the first human inhabitants of the area. While the collection is still small—just one case of arrowheads, a hammer stone, hunting tools, and a masso for grinding mesquite beans into flour—the pieces are well worth viewing.

#### WHAT’S NEXT?

Progress moves slowly in this small place so dependent on visitor donations and the generosity of a dedicated but modest group of members and supporters. Just as the museum is still very much a work in progress, the master plan is fluid as well. Everything is influenced by the exhibit a particular expert is willing to develop from his or

her work, or an exhibit or artifact a benefactor chooses to fund or donate. Even then, any contribution will be researched and evaluated in terms of its appropriateness for the collection.

Museum members hope you’ll be interested in joining their effort, and they definitely hope you’ll pay a visit to this special corner of California.

#### AUTHOR

**P**amela Handy and her husband, Fred, travel the country in a motor home, visiting and writing about the special places and people they encounter along the way. Death Valley, and especially the little town of Shoshone, is a frequent destination for them.



*Drawing by Betty Troxel.*

# COLORING BOOK

52

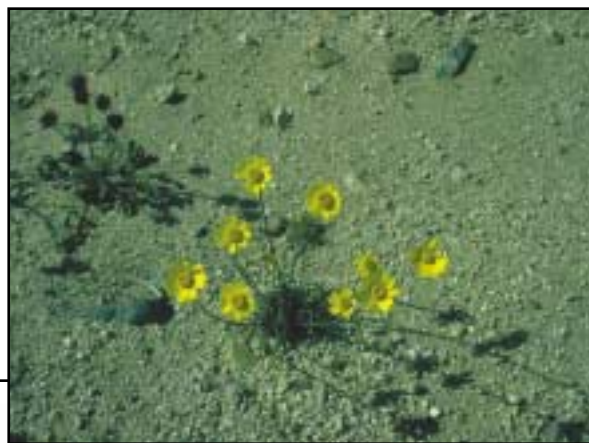
## DEATH VALLEY FLOWERS

FINE LINE DRAWINGS FOR ADULTS

COLLECT BY  
COLORING  
NO. 1

Included in the museum's collection is Betty Troxel's striking, hand-drawn poster of plants and flowers indigenous to Death Valley. Betty has followed her husband, Bennie, around the valley for decades. While Bennie looked at rocks, she looked at blooms. She became so fascinated that she began to sketch them. Bennie would often backtrack to find his missing spouse lying on her stomach in the dust, looking at the flowers' intricacies and matching their delicate colors—first to her stack of colored pencils and then to the subtle shades of silk embroidery floss. She embroidered as well as drew them.

The museum sells a coloring book of her drawings, so you may record your own impression of just the right shade of yellow for a *California coreopsis*. Beyond that, the concise sketches will help identify the plants you may encounter trekking through not-so-dead Death Valley.



### SHOSHONE MUSEUM DIRECTOR

Since 1999, the museum has had a special guiding hand, Sunny Vasquez. Sunny came to Death Valley from Oklahoma as a toddler. She discovered an inborn love for the desert and decided it would always be home. She agreed to take over the job of museum director; it has been a boon to the museum. She shows visitors around, answers questions, points out subtler items according to their particular interests, and gives lively and inviting descriptions of other Death Valley destinations. Like all the others, she has dreams for the museum's future, including the development of a truly representative display of the agriculture, artifacts and history of the Shoshone and Paiute people.

*For more information, contact the  
Shoshone Museum Association  
P.O. Box 38  
Shoshone, California 92384  
(760) 852-4414*



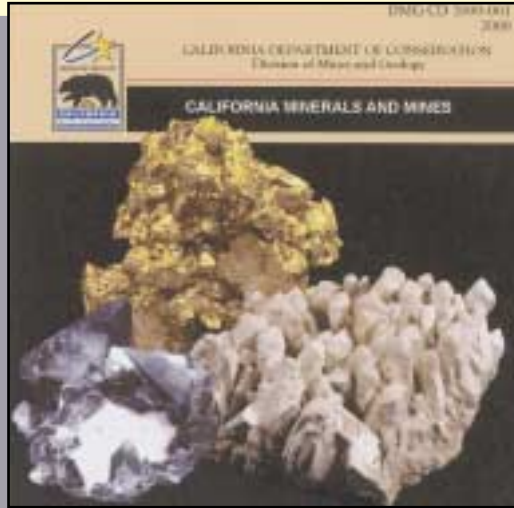
*Sunny Vasquez. Photo by Fred Handy.*



*Shoshone Museum. Photo by Max Flanery.*

—**Newly Released**—

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Skip ready to deposit into the Empire Mine. DMG Photo LS25f



Wulfenite. DMG Photo B0068



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History renders of mill Pacific Coast Home Company Works, 1918. DMG Photo A7297

# FOSSIL FINDS IN THE LOS ANGELES SUBWAY

Millions of years ago, the climate of Los Angeles was much cooler and wetter than it is today. Its lush landscape teemed with ground sloths, horses, elephants and camels—a virtual kingdom of prehistoric creatures. There were even redwood trees.

## How do we know all these things?

These fascinating revelations were brought to light by paleontologist Bruce Lander and his team of 28 scientists. They discovered thousands of fossils, many of them rare, during construction of the Metro Red Line subway project last year.

Most of the unearthed fossils date back to the late Miocene (24 to 5 million years ago) and late Pleistocene (10 to 1.8 million years ago) epochs.

The late Miocene discoveries contain some of the most diverse fauna ever uncovered. The types of marine fossils found show us that Los Angeles was under 1/2 to 1 mile of water.

Fossils from the Pleistocene give us a glimpse of Los Angeles during the Ice Age when the L.A. Basin was a brush-covered plain where animals such as mastodon, bison and camel roamed freely.

## THE MIOCENE EPOCH



MUD PECTEN OR GLASS SCALLOP

*Delectopecten vancouvernsis fernandoensis*

AGE: late Miocene, 7-8.5 million years ago



SEASTAR ("STARFISH")

*Zoroasteridae*

AGE: late Miocene, 7-8.5 million years ago

## **What did the Los Angeles Basin look like 12 million years ago?**

Water, water, and more water.

During the Miocene, the L.A. Basin was completely submerged in water. In fact, not only did the Pacific Ocean completely cover L.A., but it was in an entirely different geographic location—about 100 to 150 miles to the southeast. (For the past 40 million years, the San Andreas Fault has consistently been pushing the entire West Coast northward at a rate of 2 1/2 inches a year and continues to do so.)

During this epoch, the waters were subtropical and deep. Marine fossils uncovered during the excavations were of animals that could only live in extremely deep water. Toward the end of the Miocene, these creatures lived in water 1/2 to 1 mile deep!

### What was the climate like during the Miocene?

Back then, there was plenty of “liquid sunshine” in southern California. The climate was subtropical and it rained...a lot. The average annual rainfall was 30-40 inches. Today, the average annual rainfall in southern California is around 12 inches.

Miocene-era fossils found during the Metro Red Line subway excavation date back 7 to 8.5 million years ago. They represent the most diverse fish fauna collection ever reported from this period. Nearly 3,000 marine fossil specimens, representing almost 100 species are included.



DEEP-SEA SMELT

*Bathylagus*

*Anterior skeleton*

AGE: late Miocene, 7-8.5 million years ago

*Bathylagus* remains have been found in many marine Miocene diatomite and shale deposits in southern California. It probably was similar to living deep-sea smelts, which live at depths of greater than 1,000 feet. A full-grown smelt reaches about 10 inches long and feeds on crustaceans.

Today's smelts live in the Atlantic and Antarctic oceans, as well as the Pacific coast of Central and North America.

## THE PLEISTOCENE EPOCH



EXTINCT CAMEL

*Camelops hesternus*

*Left and right first upper molars*

AGE: late Pleistocene, 10,000-280,000 years ago.



The renowned Ice Age occurred during the Pleistocene (1.8 million to 10,000 years ago). Most of the northern continents were covered by enormous glaciers or ice sheets. Beginning 1.7 million years ago, ice sheets began to develop on the highlands in North America and Europe and spread over the northern half of North America and a quarter of Eurasia.

Although it became cooler in the Los Angeles Basin during this time, the temperature remained above freezing. The weather in the Santa Monica Mountains was even cool enough for redwoods.

By this time, the surrounding mountains of the area had emerged. The glacier-type conditions so characteristic throughout the Northern Hemisphere existed on the peaks of the San Bernardino and San Gabriel mountains.

Probably the biggest change to the terrain was the Pacific Ocean; it had retreated almost to its present shoreline. In its place were flat open grassy and brush-covered plains that stretched across the basin.

Roaming the basin were some pretty amazing animals, including the mammoth, mastodon, saber-toothed cat, giant ground sloth and cave bear. Many of the animals living in this region at this time came here over the Bering Land Bridge, which connected northeast Asia and northwest North America, or from South America.

At the Metro Red Line subway, workers uncovered bones and teeth of the Great Ground Sloth and an Ancient Bison. They also discovered parts of "fossilized" cottonwood and incense cedar trees that were over 45,000 years old. Most of the animal fossils unearthed are similar to the types of fossils found at the nearby La Brea Tar pits and date back 28,000-10,000 years ago.

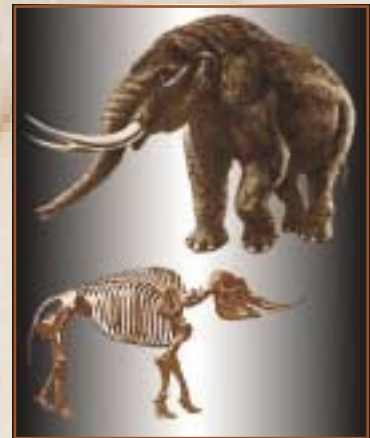


#### AMERICAN MASTODON

*Mammot americanum*

*Portion of second lower molar*

AGE: late Pleistocene, 10,000-280,000 years ago.



Although they had tusks and a trunk, mastodons are only distantly related to modern elephants. Mastodons originated in Africa and migrated to North America about 15 million years ago. They survived in North America until the end of the last Ice Age about 10,000 years ago.

## PALYNOLOGY

### THE STUDY OF POLLEN



While a relatively unknown science, palynology, is one of the best way to understand ancient environments and their climates. Through modeling, this information helps us to understand future weather and environmental patterns.

As standard practice, pollen is separated from ancient fossil sediment and from the earth in the immediate vicinity of fossil finds. The specimens are then sent to a lab for analysis.

At the Metro Line subway dig, pollen samples of "mormon tea" (as well as other arid-adapted plants) were found. Today "mormon tea" can be found in the Mojave Desert. Such a find tells us that the climate Los Angeles 9,000 years ago was drier and more extreme, with hotter summers and colder winters than today.

For more information about the fossil finds at the Los Angeles Metro subway, call Metro Transportation (MTA) Media Relations at 213-922-2712.

Visit MTA's Underground website at [www.MTA.net](http://www.MTA.net) for pictures and learn more about the excavations.

The fossils are permanently displayed at MTA's

**MTA Headquarters**  
**One Gateway Center**  
**15th floor**  
**Los Angeles, CA**  
**90012**

## WHAT'S IT LIKE TO BE A PALEONTOLOGIST?

Dr. Bruce Lander is a paleontological and environmental consultant. He has been instrumental in recovering, preserving and analyzing fossil specimens throughout Los Angeles.

### **Q. What does a paleontologist do?**

- A.** Well, first of all, paleontology is the study of ancient life through the search and discovery of fossils (a remnant, impression or trace of an animal or plant of past geologic ages that has been preserved in the earth's crust). As a paleontologist, my job is to recover, preserve and analyze all types of fossil specimens found under the earth's surface.



### **Q. What does it take to be a good paleontologist?**

- A.** I think patience. A lot of patience. Paleontology is painstaking and often very monotonous work. It requires a great deal of observational skill. A fossil isn't very useful without recording an enormous amount of minute data. Where was it found? What position was it found? What was the fossil found with? Every small detail can offer the most invaluable clues of what the environment was like millions of years ago.

### **Q. When planning a dig, what are some of the things you need to take into account?**

- A.** Step one in planning a dig is to determine whether or not there is a high likelihood that any fossils exist in the spot that has been selected for digging. This is usually done through a review of geologic maps, scientific literature and museum records. Next we need to determine the approximate depth where the fossils are most likely to be found. (At the subway site, most fossils, including a mammoth tusk were found only 35 feet beneath the earth's surface. In one case, a mastodon skull was discovered barely 6 feet beneath the surface.) We usually arrive at the excavation site only after construction has hit a predetermined depth. A monitor is on site for the duration of construction to examine freshly exposed rock and to meticulously comb through the material excavated by construction equipment.

### **Q. What is the significance of the Metro Red Line subway discoveries?**

- A.** The fossils recovered from the subway are scientifically important because they represent in some cases, the first or oldest record of their respective species. For example, we found the largest collection of marine species ever unearthed in the Los Angeles area. We also learned—through some of the deep water fish species recovered—that during the late Miocene epoch Los Angeles was submerged more than a half mile underwater.

### **Q. What significance do the findings of ancient fossils have on the present?**

- A.** We don't live in a historical vacuum. The climatic history of humankind runs in cycles. So what occurred thousands of years ago (like the Ice Age), could very well happen again. Studying the past enables us to develop models to help us adapt and prepare for similar events that may occur.

### **Q. What advice can you give those who want to become a paleontologist?**

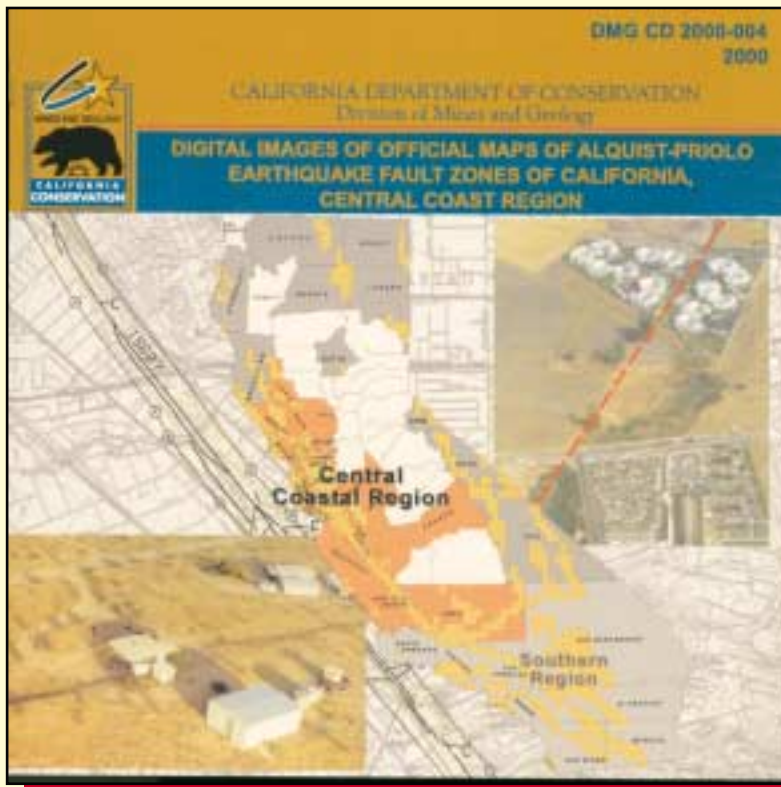
- A.** Our jobs are unfortunately the ones that are in peril when funding cuts occur. However, if somebody wants to become a paleontologist, I would recommend getting the broadest base of science education possible. For example, don't just limit yourself to studying paleontology. Include such topics as biology and geology as well. I would also encourage students to obtain as many computer skills as possible.

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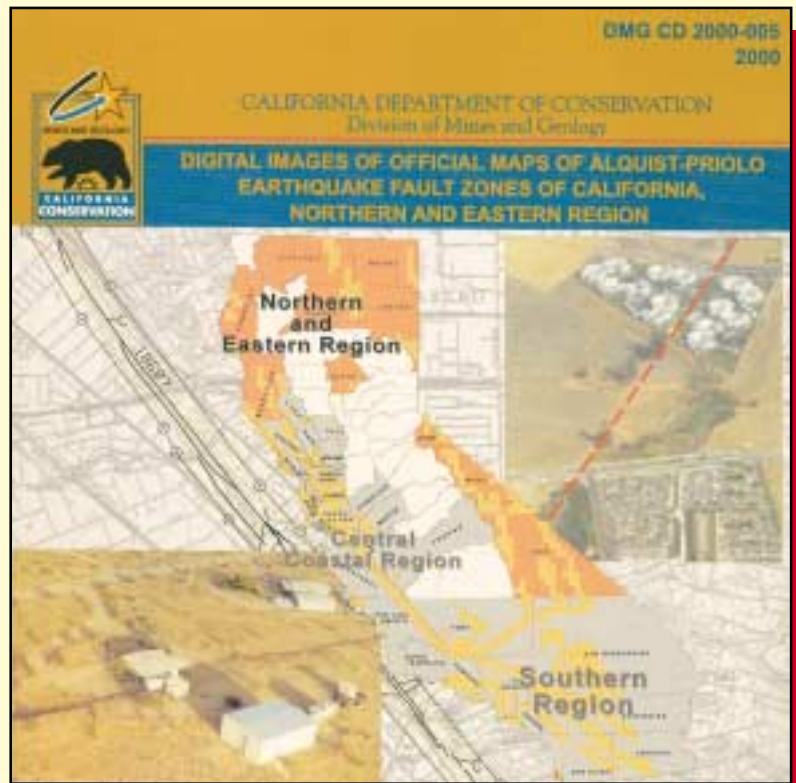


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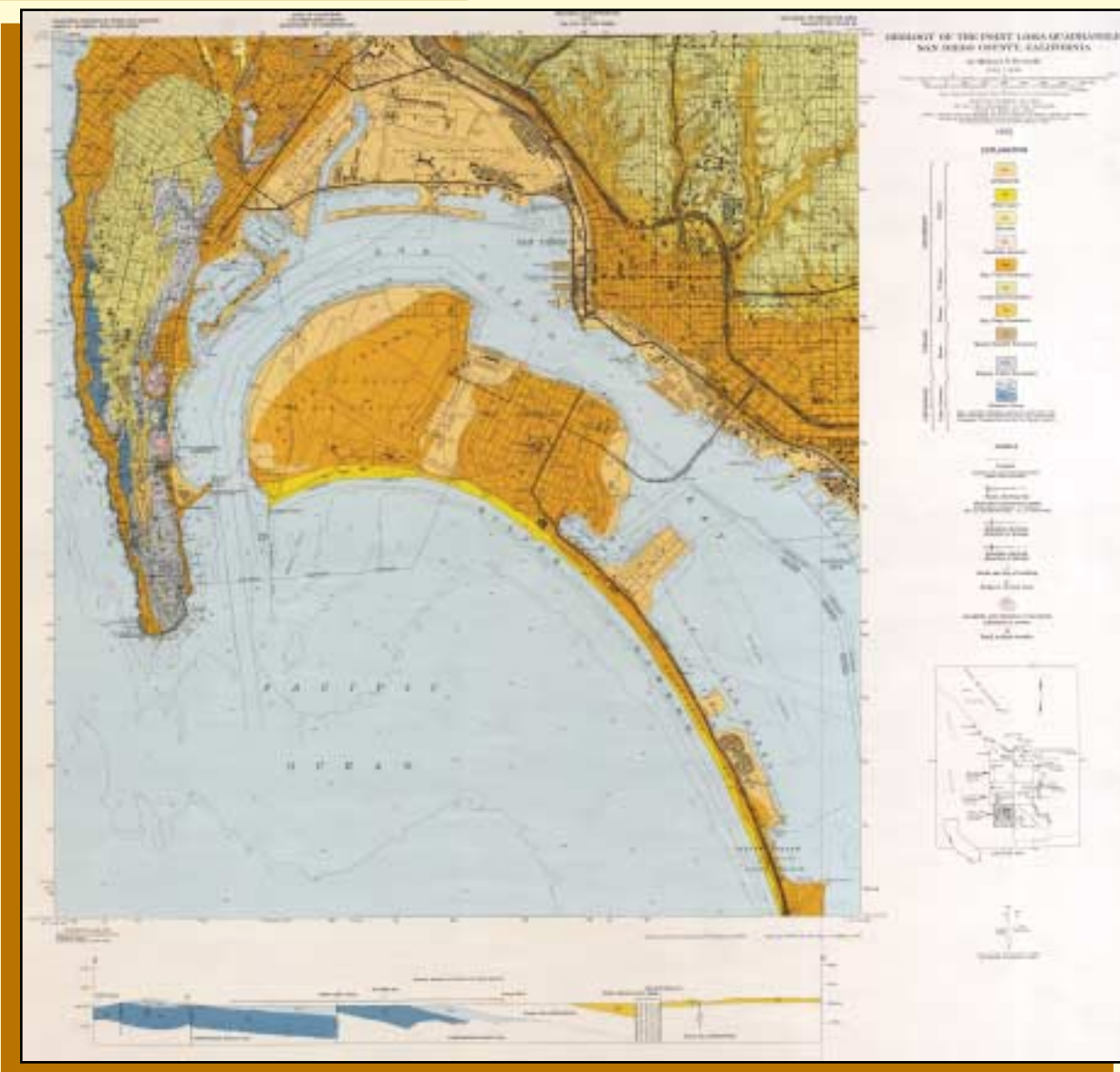
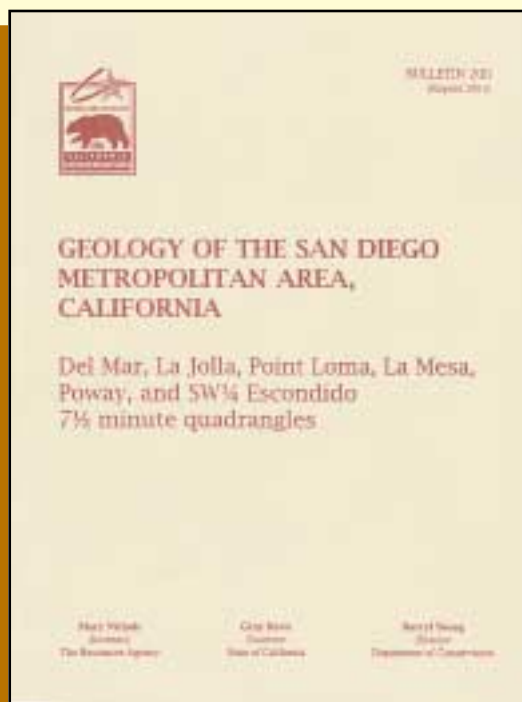
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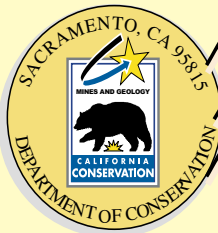
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